The Thirty Meter Telescope Site Conditions Monitoring System

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The Thirty Meter Telescope Site Conditions Monitoring System

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Abstract. We examine the experiences and ideas from operating observatories regarding the measurements of the characteristics of the atmosphere that must be gathered within the locality of the observatory in order to support safe, efficient and scientifically optimized observatory operations as well as commissioning, performance monitoring and support the scientific analysis of telescope observations. We describe the expected requirements for the measurement capabilities of the the TMT Site Conditions Monitoring System (SCMS) and discuss how these plans are being developed with input from staff at operating observatories and active observational astronomers.

1. Introduction

The Thirty Meter Telescope Project moved into the construction phase in May 2014. The nominal time for the end of construction and beginning of early science operations and full commissioning is 2024. At the end of construction the present plan calls for a multiple laser guide star system supporting a fully functioning MCAO system. The MCAO system will feed a dual channel diffraction limited NIR imager and IFU instrument and an AO enhanced NIR multi-object spectrograph. An optical seeing limited wide field optical spectrograph will be available. Both classical and queue scheduled observing modes will be provided. Commissioning will include optimizing the AO system, developing observing and data reduction procedures and optimizing the image quality through the use of the enclosure vents.

The present plan for the SCMS is based on the TMT site testing system [2] (see Section 2). However a system to evaluate a site for an observatory has different requirements to a system that supports observatory operations and commissioning. It is important to explore the requirements for the TMT SCMS.

The TMT SCMS will work in a complimentary way with the Engineering Sensor (ESEN) system. The ESEN consists of many air and structural temperature probes, sonic anemometers, precipitation and humidity sensors, accelerometers to measure vibrations and tilt meters to measure structural deformations on and around the telescope.

2. Present Requirements for the SCMS

The TMT SCMS is required to support all of the commissioning and operations activities as well as provide input for local conditions forecasting and provide astronomers with information on local conditions during their observations to enable treatment of systematic effects in their astronomical data that may limit interpretation.

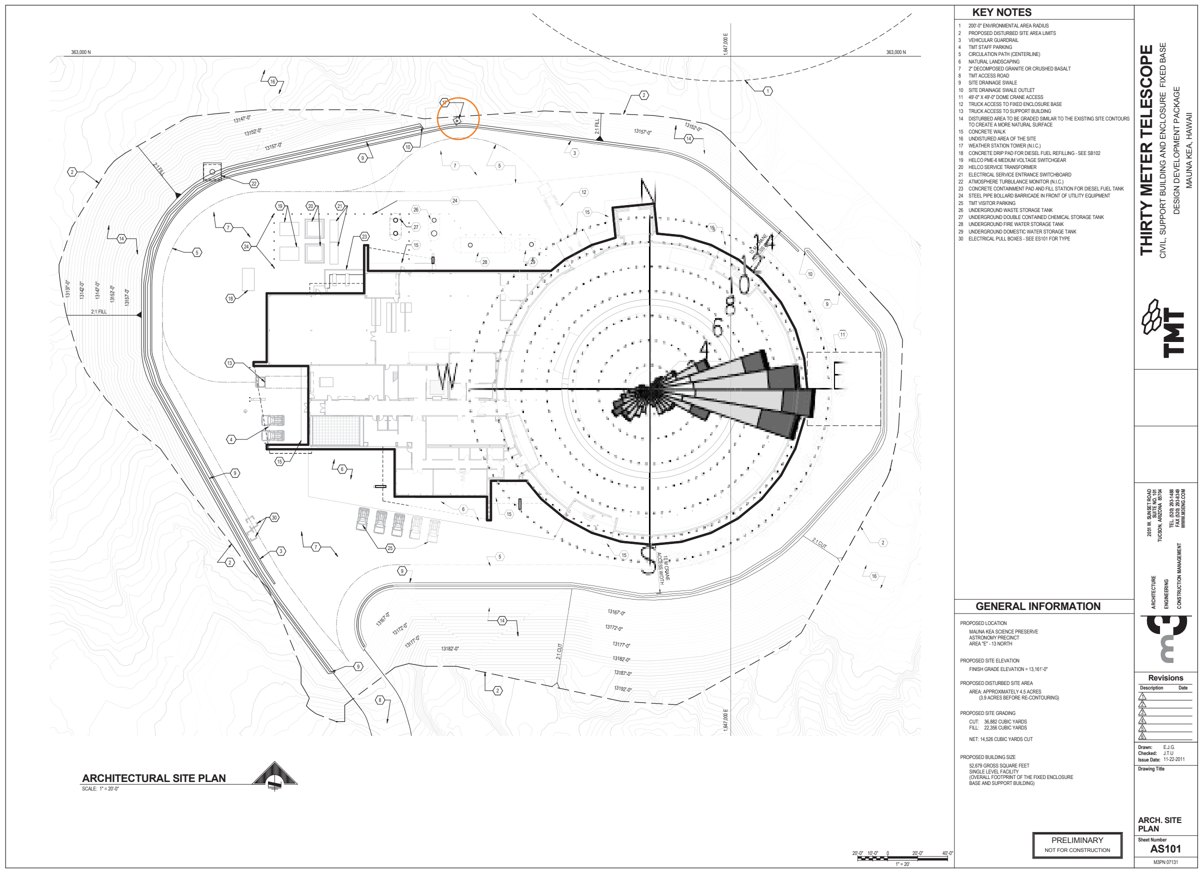

Figure 1. Plan of the TMT observatory at the its on Maunakea, showing the location of the SCMS (circled near top middle) with the measured wind rose super-imposed over the location of the telescope pintle bearing.

The location of the main part of the SCMS will be quite close to the observatory, see Figure 1 and the validity of local seeing measurements will be significantly reduced. The main components of the site testing system were a MASS/DIMM to monitor the atmospheric turbulence profile and integrated seeing, an All-Sky Camera (ASCA) for cloud and light pollution measurements [4], an Automated Weather Station (AWS) with a full suite of typical meteorological instrumentation, Sonic Anemometers at many locations around the observatory and an Infra-Red radiometer (IRMA) device to measure the PWV [1]. Sonic anemometers have been baselined as both wind and optical turbulence sensors [5] to be located around the telescope enclosure vents, working with sonic anemometers located on the telescope itself so that the optimal vent configurations can be derived to give the best image quality for a given set of external wind and temperature conditions and to help diagnose image quality problems that may or may not be related to wind flow through the enclosure.

3. Re-examining the SCMS Requirements

3.1. Information Gathering

A lot of communications were carried with operations staff at the Gemini North, Paranal, IRTF, CFHT and Keck observatories, with astronomers that use AO corrected images for extremely precise astrometric measurements, mid-IR spectroscopic and seeing limited optical observations and with meteorologists that make forecasts of the astronomical observing conditions for Maunakea. All were asked what types of atmospheric measurements are required for their specific needs. Where appropriate specific requirements were extrapolated or adjusted for the TMT.

3.2. Telescope Operations

In telescope operations the SCMS measurements would be used for optimizing queue scheduled observations, e.g to decide whether to follow or change the plan of scheduled observations. To do this would require the measurements listed in Table 1. Also listed in Table 1 are the measurements needed to ensure safe telescope operations and to support the segment alignment process because segment alignment works best during periods of good seeing.

Table 1. List of SCMS measurements needed for telescope operations, commissioning and performance monitoring and supporting scientific analysis.

Queue implementation and forecasting support	Clouds, transparency, sky brightness, PWV, seeing Turbulence profile if using AM2 Wind speed and direction
Optimized telescope performance (wind shake, vents, pointing)	Wind speed and direction
APS operations (M1 alignment)	R_0 and seeing
Telescope safety	Fog, dust, wind speed and direction, humidity Dew point (air pressure, temperature, humidity) Solar radiation
MCAO performance estimation and monitoring	R_0, seeing, turbulence profile Wind speed and direction
Seeing limited instrument performance evaluation	Transparency, cloud cover, seeing
Scientific interpretation	Wind speed and direction, air temperature, air pressure Sky brightness, PWV, seeing, transparency Turbulence profile

Another important aspect of SCMS support of operations is the supporting of conditions forecasting by providing information on observing and atmospheric conditions to the enable anchoring of forecast models and fine tuning. The Mauna Kea Weather Center carries out this work and continually seeks to improve the quality of forecasts and respond to the needs of the observatories on Maunakea.

3.3. Commissioning and Performance Monitoring

Observatory commissioning must be carried out whilst ensuring the safety of the telescope and other equipment. A good understanding of the atmospheric characteristics will greatly enhance the ability to isolate and diagnose problems that all ultimately affect image quality. Understanding the fundamental expected image quality due to the atmosphere and being able to identify the cause of any degradation, be it due to incorrect AO correction, wind induced image jitter or primary mirror segment mis-alignment will be a powerful utility during the commissioning period. Table 1 lists the measurements needed during commissioning.

There was no identified need for high fidelity wind and optical turbulence measurements in the telescope enclosure. This is due to existing telescopes not needing such measurements, however there is uncertainty about whether this can scale up to an observatory the size of the TMT. The baseline plan for the TMT SCMS and Engineering Sensors (ESEN) proposes for sonic anemometers to be located in the enclosure vents and on the telescope structure and requires that the communications and power necessary to support such an array of sensors is in place.

3.4. Science Analysis

There are general types of measurements that are often considered by astronomers when interpreting their observations, these are listed in Table 1. However a common experience is that the scientific interpretation is greatly assisted with the availability of AO telemetry, telescope control system and Engineering Sensor (ESEN) measurements. It should be noted that the utility of measuring the turbulence profile is minimal because of the availability of AO telemetry and dominance of optical aberrations in the instrument over any smaller AO related effects.

Here we present two examples of sets of observations whose analysis and interpretation is limited by effects that can be better understood with appropriate measurements from an SCMS in the first case and from engineering data in both cases. This is done to illustrate that the SCMS must be considered part of a suite of sources for observatory related information that may be needed to maximize the scientific output of the observatory.

3.4.1. Uncorrected artifacts in diffraction limited images

The quality of correction of an AO system varies with time, on the most rapid timescales this is purely due to limitations in the wavefront sensing and correction abilities of the system. Some AO systems introduce long lived features that mimic diffraction patterns. When bright, these patterns are easy to identify but if two or more faint patterns below the detection limit coincide then they may create a false detectable 'source' in the image.

Identification of transient features in AO corrected images is a major limitation. Figure 2 shows the Milky Way Galactic Center and the G2 object that both moved and showed large variations in brightness. Discerning between variable artifacts and the combination of real motion and brightness variations was a very difficult task.

AO telemetry is extremely useful for discerning between real transient sources and variable artifacts. Also the number of artifacts has some dependence on seeing. Thus a combination of SCMS seeing measurements and AO telemetry is needed.

3.4.2. 1.27s oscillation in rapid Keck spectroscopy

Telescope control systems are not perfect and can introduce image motion. Figure 3 shows rapid t_{samp}=72ms optical spectroscopic observations of the Cataclysmic Variable AE Aqr that were folded on the 33 second spin period of the magnetic white dwarf [3]. During the analysis of the observations relatively large oscillations were found at a period of 1.27s in both the wavelength dispersion direction (seen in variations in wavelength of static atmospheric absorption lines) and the temporal direction (seen in variations in the flux levels). These 1.27s

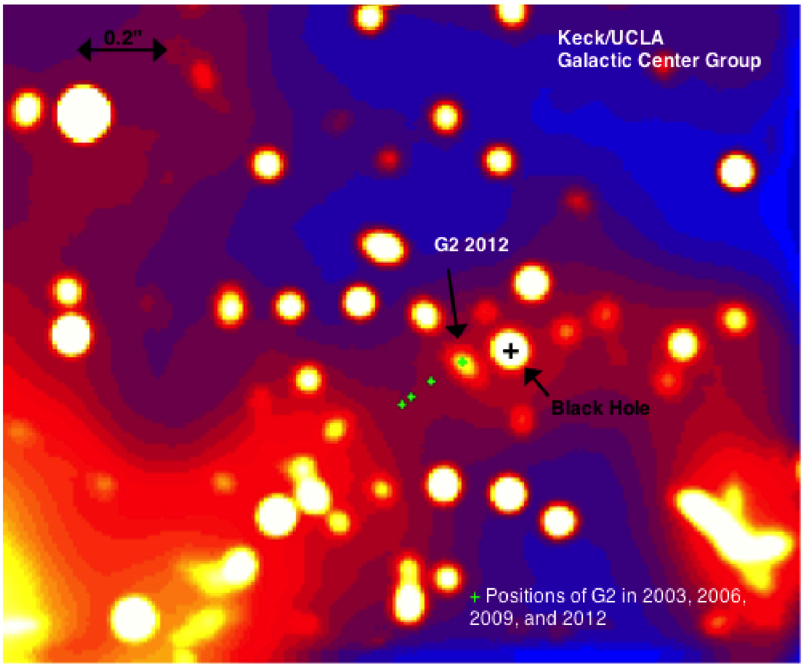

Figure 2. The G2 object and its path toward the SgrA* SMBH at the center of the Milky Way. Identifying the G2 object along its path was greatly complicated by the occurrence of false positive sources created by mis-corrections from the AO system and the G2's intrinsic variability.

variations corrupted and masked the very subtle intrinsic signals in the data. However the same 1.27s variation was seen in other objects observed during the same observing run and enquiries with the observatory engineers identified the 1.27s period as being related to an instability or resonance in the telescope drive system. Applying appropriate corrections to the data to cancel the 1.27s signal allowed the signature of the white dwarf rotation to be extracted.

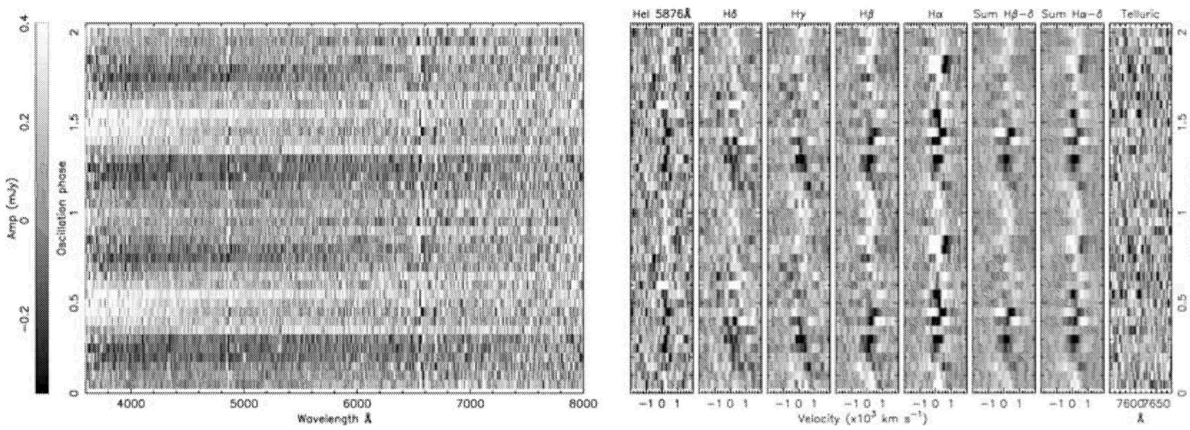

Figure 3. Trailed spectrograms of AE Aqr folded into 20 phase bins on 33 second white dwarf spin period and repeated for clarity. The left image shows the continuum emission with the pulsation amplitude rising toward the blue and the major peak occurring at phase 0.5, the minor at phase 1. The right panel zooms in on the emission lines and S curve type signatures can be clearly seen.

4. Conclusions

Clearly some form of an SCMS is a critical component for telescope operations. An important aspect that was identified was the need for engineering data that would be used in concert with site conditions measurements for all operations, commissioning and science analysis activities. Engineering data would include but isn't limited to AO telemetry, observatory engineering sensors and control system telemetry. Interestingly, the need for optical turbulence profiles was deemed 'interesting' but not of high importance, for example, for astrometric measurements of AO corrected images, instrumental distortion mapping will dominate over systematic AO correction limitations and also there is not a strong need for turbulence profiles during operations unless an adaptable secondary mirror is being used for ground layer AO corrections. Seeing and wind speed and direction measurements are used for many different aspects and are thus high priority measurements for an SCMS.

5. Acknowledgements

Many members of staff at operating observatories and active observational astronomers have provided input to help guide the development of technical requirements for the TMT SCMS.

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